REDUCTION OF ENERGY CONSUMPTION AND LATENCY IN COGNITIVE WBAN USING LDPC ERROR CORRCTING CODES

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Master of technology
In
Electrical Engineering
(Electronic Systems and Communication)

By

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Under the guidance of

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Dedicated to…

My Parents and my well wishers

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA – 769008, ODISHA, INDIA

Certificate

This is to certify that the work done in thesis "**Reduction of energy consumption and latency in cognitive WBAN using LDPC error correcting codes"** by **Chintala Durga Prasad (214EE1407)** in partial fulfilment of the requirements for the award of the degree of Master of Technology in Electrical Engineering during session 2014-2016 in the Department of Electrical Engineering, National Institute of Technology Rourkela is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Place: NIT Rourkela

Date: 27th May2016

Prof. Susmita Das

Associate Professor

Acknowledgement

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NIT Rourkela

May 27, 2016

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Abstract

Wireless sensors placed inside or mounted on the human body are called as Wireless Body area networks (WBAN). Wireless networks have IEEE standard 802.15 where Wireless Body area networks has the standard 802.15.6. Sensors present in WBAN are either implanted or wearable. Sensors placed inside body are called implanted sensors and mounted or attached on body or surroundings of body are called wearable sensors. These sensors collect the biological information of humans like heartbeat, ECG, blood pressure (BP) etc. and transfers it to the device personal digital assistance (PDA). PDA forwards this information to nearby medical centre to take necessary actions.

Wireless body area network has been implemented to monitor the human body systems to detect and cure the diseases. Lifetime and Latency are the major concerns in for Wireless body area network. Due to the signal transmission takes place in or around the body in WBAN, Packet Error Rate has been affected because of channel fading and collisions in the channel due to the existence of other wireless devices. Therefore, latency and lifetime of the sensors very crucial. To reduce these issues, cognitive radio (CR) armed Wireless body area network should be a better option. Here, Reed Solomon and LDPC error correcting mechanism for CR-armed Wireless body area network has been proposed. Various issues in Cognitive Radio networks have been investigated till date to cope with latency and energy utilization. Error control techniques have not explored for Cognitive Radio networks and the existing error correcting mechanism for WSNs should not be imposed to Cognitive Radio network due to the mechanism of adaptive spectrum access mechanism. The method proposed here selects the routes and number of hops from source to sink adaptively and alters the redundancy to reduce the expected energy and latency utilization. The simulation results show that the proposed mechanism gives better results with the view of energy, latency consumption in the multihop CR armed Wireless body area network.

Contents

ABBREVIATIONS

WBAN	:	Wireless Body Area Network
PDA	:	Personal Digital Assistant
BPSK	:	Binary Phase Shift Keying
RS	:	Reed Solomon
CR	:	Cognitive Radio
ARQ	:	Automatic repeat request
BER	:	Bit Error Rate
SNR	:	Signal to Noise Ratio
CFEC	:	Cognitive Forward Error Correction
FEC	:	Forward Error Correction
DSA	:	Dynamic Spectrum Access
PU	:	Primary User
SU	:	Secondary User
BP	:	Blood Pressure
ECG	:	Electro Cardiogram
AWGN	:	Additive White Gaussian Noise
ECC	:	Error Correcting Code

NOMENCLATURE

T_{on}	:	Duration that PU occupied the channel
T_{off}	:	Duration that PU not occupied the channel
L	:	Length of the message
H	:	Length of the header
R	:	Data rate of Secondary User in channel
P_b	:	BER probability
PER_{coll}	:	PER due to collision of users
PER_{ARQ}	:	PER of ARQ technique at receiver
PER_{RS}	:	PER of RS technique at receiver
PER_{LDPC}	:	PER of LDPC technique at receiver
$E[N]$	:	Amount of Expected transmissions
$E[P_{TX}]$	:	Transmitted power Expected
t_{TX}	:	Transmission time of Secondary User
$E[P_{RX}]$	:	Receiver power Expected
T_{RX}	:	Reception time of Secondary User
R_C	:	Code rate of ECC
E_{cons}	:	Energy consumption for single hop transmission

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Introduction

1.1 Overview

The fundamental duty of the Wireless networks technologies is to support the modern networks to connect a person at anytime and anywhere. WBAN, WLAN, WPAN are some of the examples of wireless network. [1]. WBAN has become very important technology due to its services in the healthcare of humans by detecting, diagnosing and curing the diseases. Architecture of Wireless Body Area Network comprises wireless sensors which collects data from body, central unit which controls all the sensors and wireless Personal Device which acts like a gateway between central unit and medical centre. [2]. Wireless sensor placed inside body (implanted sensors) or mounted on the body surface. These sensors collect information from body and sends it to control unit. Then it forwards it to nearby medical centre.

Traditionally, data transfer in Wireless Body Area Network through ZigBee. It works in ISM band. So, chances for the interference and collisions are more in this band due to large number of devices works in the same band. This interference leads to more energy and latency consumption. In Wireless body area network sensors place inside body. It is not possible to take the sensors out and chare. So, energy consumption should be less and more energy consumption harms the body tissues also. Secondly, information transferred from the sensors should be reliable with less errors and with less latency at emergency situations.

Here, Cognitive Radio (CR) based Wireless body area network is proposed which should be a promising solution for these challenges.CR solves these problems by introducing Dynamic Spectrum Access. There are two types of users in CR named primary User (PU) and Secondary User (SU) where latter is differentiated with former by having cognitive capability. Secondary Users can find the vacant channels and access those by changing its operating parameters according to the vacant channel. SU can choose a channel having better channel conditions in terms of channel fading and collisions [5].

Error correcting techniques are used to minimize the Packet Error Rate (PER). By this, energy and time consumption can be minimized. Error correcting techniques Automatic Repeat Request (ARQ), LDPC and RS are investigated [7].

1.2 Literature survey

[1] Explained different standards of wireless technologies and highlighted Body Area Network and its applications and discussed about various short range technologies supports BANs.

[2] described the importance of WBAN in human healthcare and proposed a conceptual design of virtual doctor server (VDS) to serve the patients.

[3] Explained the various channel models that can be considered for Body Area Networks. The propagation models, path loss models etc. for various channels of WBAN has been studied in this work.

[6] Derived analytical calculations for the efficient energy consumption in terms of PER in cooperative communication.

[7] Describes about the combination of Cognitive Radio with WBAN and proposed a new error correcting mechanism CFEC which is combination of FEC and ARQ.

[9] Describes the small description on wireless body area network, adoption of CR in wireless sensor networks and advantages of combination of cognitive radio with wireless sensor network. Research challenges in CR based WSN are also discussed in this paper.

[12] Differentiated the LDPC codes as regular and irregular and compared these two with the view of error controlling capability and shown the superiority of irregular code s over regular codes.

[14] Checked the performance of various Reed-Solomon error correcting techniques to correct the errors with and without interleaver. It explained that the block codes can be performed better with efficient interlaevers.

1.3 Objective

The basic aim of this study is reducing Energy and time consumption during transmission of information from sender to receiver using different error correcting techniques.

1. To Study and analyse the existing Error correcting techniques and finding the demerits in those techniques.

2. To develop a network model for CR armed Wireless Body Area Network which contains multiple paths from source and destination.

3. To Improve the Energy consumption and delay time by employing new error correcting techniques and compare with existing techniques.

1.4 Thesis Contribution

Wireless Body Area Network is being widely used for the continuous healthcare system that permits the patient health to be monitored and points the position of the person at any time. The ultimate goal of this work is to receive the medical information transmitted in the form biological signals, accurately.

The contribution of the thesis can be described as follows:

- Cognitive radio based Wireless Body Area Network system is developed.
- Expressions for latency and Energy utilization are derived for Cognitive radio based Wireless Body Area Network model.
- Error correcting techniques Low Density parity check and Reed Solomon are suggested and are compared with the performance of conventional Automatic Repeat Request error controlling code.

1.5 Thesis Organization

The thesis is divided into 5 sections. This present section delivers a precise introduction for Wireless Body Area Network, Patient Monitoring System, Error correction techniques. The literature survey done, motivation, objective of work and contribution of the thesis is briefed in the various subsections. And final subsection delivers how the thesis have been organized.

Chapter 2: This delivers the background of WBAN. It includes brief introduction to the application of WBAN in modern healthcare system, overview of cognitive radio, applications of CR in WSN, system model of CR armed Wireless Body Area Network and energy consumption analysis in terms of time delay.

Chapter 3: In this chapter, the existing conventional equalization techniques ARQ and Reed Solomon have been considered. Comparison of ARQ and Reed Solomon is done with respect to simulation study

Chapter 4: The fourth chapter describes the proposed error correcting technique LDPC codes for better energy consumption and time consumption. Comparison among LDPC, Reed Solomon and ARQ has been done on the basis of Energy consumption and time duration. Simulation results have been obtained to validate the superiority of LDPC codes and confirm LDPC, RS outperform the conventional technique ARQ.

Chapter 5: The last chapter gives the conclusion of the total study and also delivers the scope for future research.

2

Study of cognitive Wireless Body Area Network

2.1 Introduction:

WBAN is network for ubiquitous sensing of human body used for detecting and diagnosing the human diseases. WBAN contains sensors, which collects the data of human body and sends it to a hub which may be a gadget like smart phone. WBAN sensors may be implantable or mounted on the body surface. Sensors placed inside the body are called implanted sensors and the sensors placed on the body surface are called non- implanted sensors. These sensors sends information to the hub then it transmits that information to the medical centre where this data is subjected to analyse and take relevant action according to the situation like prescribing medicines or informing to emergency services.

2.2 Applications of Body Area Network:

Likewise remaining wireless sensor networks, providing reliable system for transmitting data like voice or picture data through wireless channels is the basic function of wireless body area network. Applications of WBAN can be categorized in different ways. Here, Applications of WBAN are divided into two main categories.

(1) Applications for healthcare and medication, and

(2) Assisting disabled persons

2.2.1 Medical and Healthcare Applications

BAN is mainly used for monitoring signals of human body and avail it for the medical assistance and dosing. Figure 2.1 [1] shows an instinctive perspective of automatic treatment and medical dosing process. The automatic medical treatment and dosing can be treated as closed loop control system. This process can be explained in three steps. In the first step, medical sensors attached to a person collects critical healthcare data. This data collected by the sensors is automatically redirects to the command unit. In the next step, command unit examine the received signals and prescribes the corresponding method of treatment or dosing. The command unit forwards the commands to action unit based on the decision taken by them. In the last step, the action unit gives the dosing or treatment to the person accordingly. After finishing of dosing or treatment, sensors will starts collecting updated vital healthcare data on a pre-set time interval and a new circulation of closed loop system will begin.

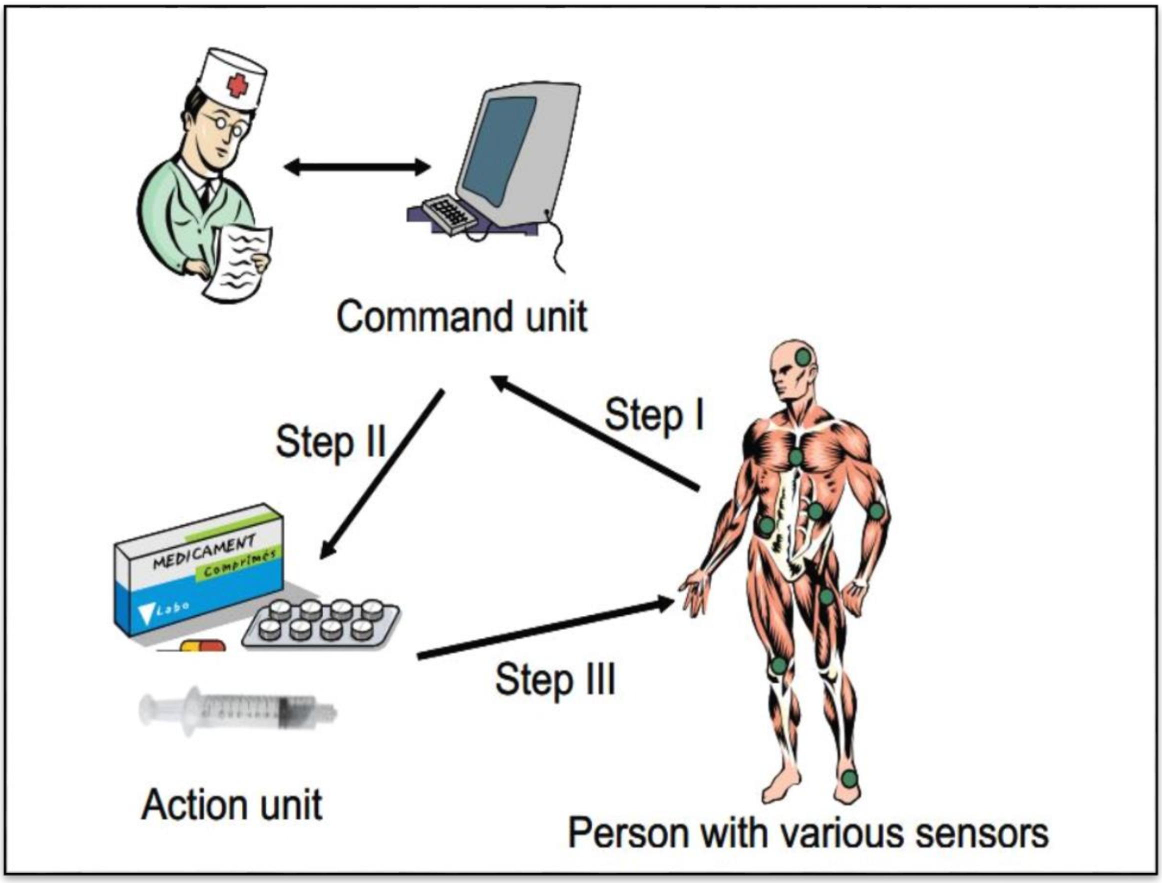

Figure 2.1 closed loop system for adaptive treatment and dosing [5]

This concept of closed loop network could be observed in real life applicaications like pacemaker. Pacemaker is an electronic device which is used in adjusting the heartbeat of a person. The important health care data like Blood Pressure (BP), heart beat and the signals like Electro cardio gram (ECG) and electro encephalo graphy (EEG) and other signals can be collected and transmitted.

2.2.2 Assisting disabled persons:

BAN can be used in wide spread of applications. The sensors which are placed or mounted on the body are also comes under wireless body area network. WBAN can assist visual disabled persons by make them wearing spectacles where we attach a video camera to it. This camera are useful in detecting the things like vacant seats in the vehicles and staircases. And radars can be attached to the stick took by the person which is used for ranging the position and to inform the desired route and so on.

2.3 Introduction to Cognitive Radio:

CR is a smart wireless system that senses all the wireless channels in the surroundings and changes it parameters like frequency band, transmitting power according to the vacant channels and it is operated dynamically. The prime objective of CR is to use the radio spectrum efficiently. The process of sensing the channels and changing its parameters according to the vacant channels is called dynamic spectrum sensing.

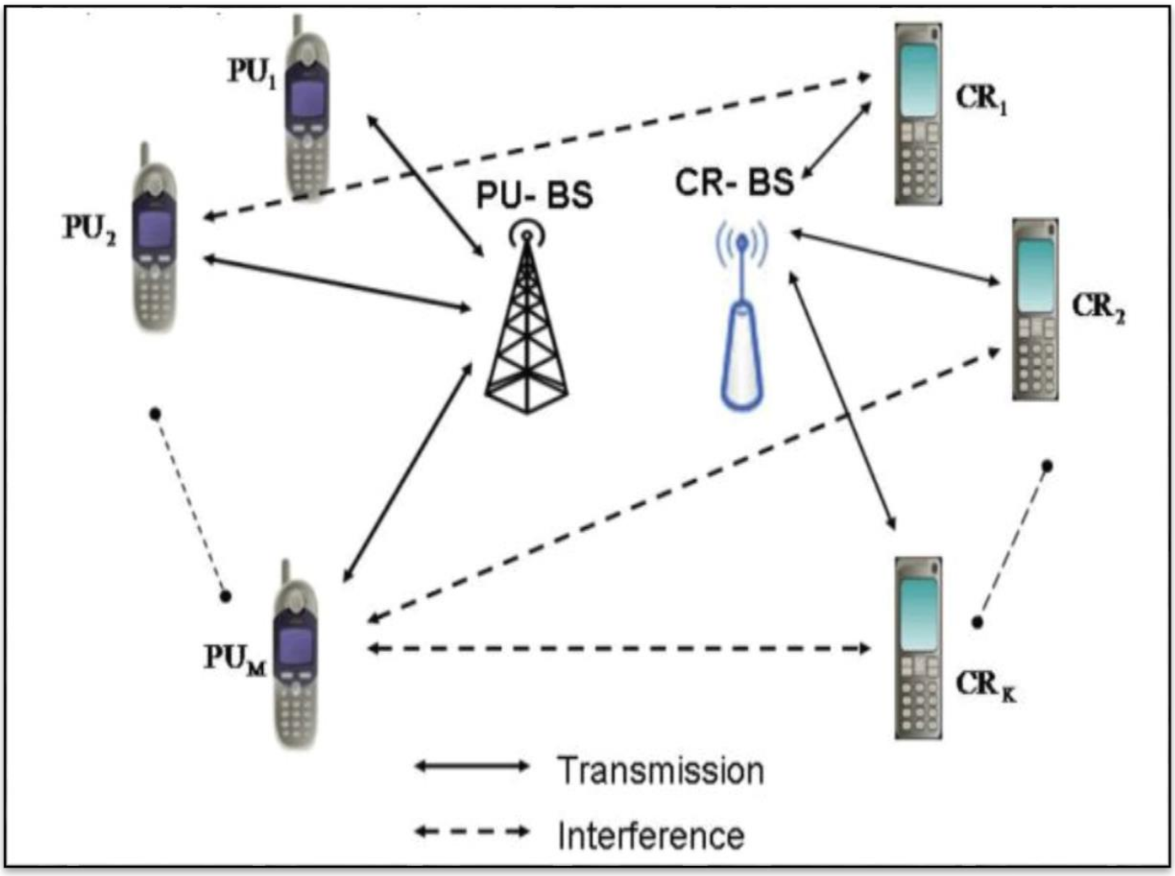

Figure 2.2 Block Diagram of Cognitive Radio with PU and SU [8]

Cognitive Radio continuously monitors its own performance.

There are two types of users present in Cognitive Radio. Those are

(1) Primary User

(2) Secondary User

Primary User: primary users are the users access the licensed spectrum. These are having higher priority in cognitive radio network.

Secondary User: secondary users are the users access unlicensed spectrum. These are having lower priority in cognitive radio network while accessing the channel. Figure 2.2 shown the scenario of cognitive Radio with Primary Users and Secondary Users.

2.4 Applications of Cognitive Radio in WSN:

CR armed Wireless Sensor Network is an upcoming prototype in Wireless Sensor network field that access the spectrum resource dynamically for bursty traffic. This network has the ability to reduce packet loss, power wastage and consumption, also maintain better quality of service. This section talks through the advantages of CR in Wireless Sensor Networks.

2.4.1 Efficient Utilization of spectrum:

The electromagnetic spectrum present in nature is the valuable boon to us. The spectrum bands which are available to usage could not be enlarged but it can be utilized efficiently. ISM bands are the only radio bands which can be accessed by anyone without having any license. For all the remaining bands one should have the license from the respective government in a country. Due to the high costs in buying radio bands, most of the researchers have concentrated at implementing new devices which works in ISM bands. That's why, ISM bands are restraining the implementation of new technologies. Secondly, most of the time bands of licensed spectrum are not utilized. CR armed WSNs can use these unutilized spectrum, which is known as white spaces, by not interrupting the licensed holders. Therefore, with very low cost unlicensed users can use the licenced spectrum. It gives the chance for the development of more new technologies in licensed bands available in that country.

2.4.2 Multiple Channels Utilization:

Traditionally, during communication Wireless Sensor Networks utilizes a single channel. Sometimes Wireless Sensor Networks, if a sensors accessed a channel and another sensor also tries to access the channel then collisions will occur. This problem is more severe in densely deployed Wireless Sensor Network. This enlarges the collision probability, and reduces the overall reliability because of high loss of packets, leads to extra power, energy usage and more time delay. Here, CR based Wireless Sensor Networks access multiple channels adaptively to reduce this problem.

2.4.3 Energy Efficiency in WSNs:

Because of the packet losses large amount of wastage of power is there. By adding CR technology in wireless sensors gives the chance to adapt the new unused channels by changing its operating parameters accordingly. So, energy utilization and wastage because of packet collisions and retransmissions can be reduced.

2.4.4 Global Operability:

Usage of spectrum bands is different in different countries. A specific spectrum band available in one country may not be available in other country. Therefore, conventional wireless sensors having a fixed operating frequency may not worthy while using globally at different geographical regions. By using CR technology in Wireless Sensor Networks, sensors can change their operating parameters like spectrum band, transmission power etc. according to the available channel. Therefore, CR based wireless sensors can be operated everywhere in the world.

In recent years, usage of wireless sensors in various areas has been raised. Wireless Sensor Networks generate packets only at the occurrence of an event otherwise those will stay silent. These correlations produce the challenges in the designing of the communication protocols for Wireless Sensor Network. Having the intelligent communication protocols in CR based Wireless Sensor Network, two sensors assigned for the same work utilizes the different spectrum bands in the spatially overlapped regions. This happens due to the presence of cooperative communication between Secondary Users in CR network, which definitely reduces the interference problems.

2.5 Cognitive Body Area Network

2.5.1 Introduction and system model:

Multi-hop CR-armed Wireless Body Area Network model as shown in Figure 2.3 [5] is considered in this study. Multi-hop relaying in wireless sensor network is becoming more popular in recent days because of its merits in the way of increase in the lifetime of network with less hops and low transmission power.

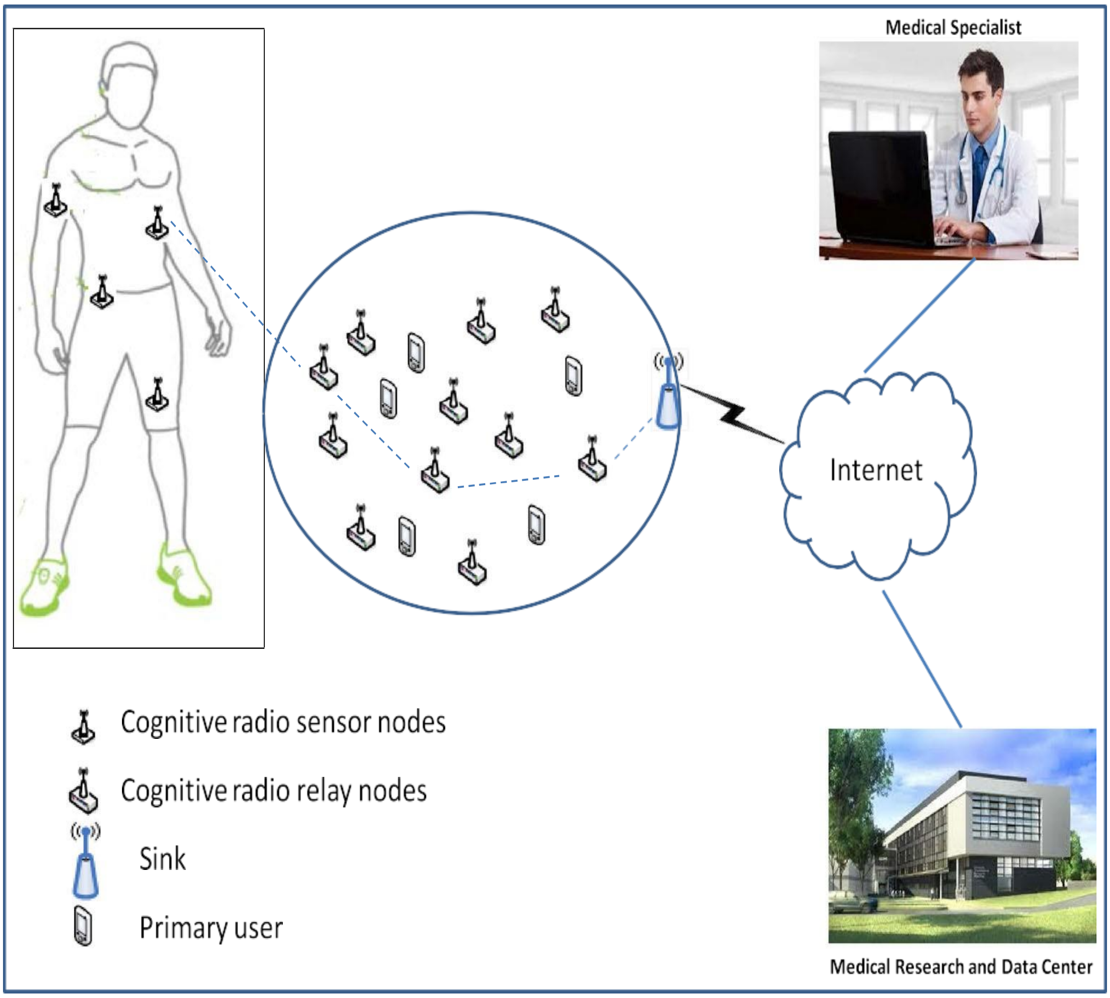

Figure 2.3 block Diagram of CR Armed Wireless Body Area Network [5]

Two types of sensors are presented in this network model: (1) data sensors, collects the biotic from human body and (2) relaying sensors, sensors which relays the data received by data sensors. Number of sensors attached on body of each patient may be different. It is considered that relaying nodes duty is to relay the data but it do not collect any biological information from the environment. With the view of latency minimum energy and time consumption in CR armed Wireless Body Area Network, the information from data sensors can be reached the destination either with single hop or multiple hops. Every node either it is a data sensor or relay sensor can adopt any available free channel and can change its operating parameters with respect to that empty channel accordingly. In this model proposed here, the sensors can access alternative routes to the destination and selects the error coding technique as well. The prime focus of this work is transferring the data signals to destination with less energy and time consumption. By reducing the hops from source to destination and the transmissions to the destination these goals can be attained. The retransmissions occur either by the noisy channels or by collisions between sensor nodes. So, the sensors should choose the best error correcting mechanism and redundancy along with the channel selection to reduce the collisions which leads to errors.

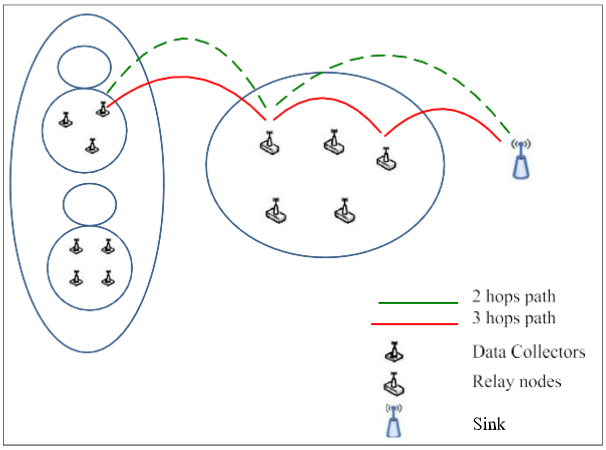

Figure 2.4 system Model for CR armed Wireless Body Area Network [5]

2.5.2 PU Activity model:

As stated previously, two kinds of users are there in Cognitive Radio network, they are, Primary User and Secondary User. In CR-armed Wireless Body Area Network, all the sensors, either gathering biological data or disseminating the collected data, work as Secondary User, and remaining sensors other than these are considered as Primary User. Secondary User can engage a channel only when it is not occupied by the Primary User. If a Primary User comes back to a channel when a Secondary User occupied the same channel then, collision will happen between the two users leads to loss of packet data. So Secondary User should be aware of Primary User while selecting a channel, therefore Primary User activity also need to be considered. The PU activity model tells whether the Primary User is active or not. Primary User is active means it occupied the channel, not active means the channel is not occupied by Primary User. Let T_{off} is taken as mean OFF time duration and T_{on} be the mean ON time. Now the probability for the Primary User to be absent (P_{roff}) and probability for the Primary User to be present (P_{ron}) can be calculated as below:

$$P_{roff} = (T_{off})/(T_{off} + T_{on}) \quad (1)$$

$$P_{on} = (T_{on})/(T_{off} + T_{on}) \quad (2)$$

If a Primary User tries to occupy a channel while Secondary User communicating on the same channel leads to a collision between Secondary User and Primary User Primary User. Collision occurred between two users even for a single bit the total packet is taken as corrupted one.

The probability of occurrence of collision, also called as PER due to collisions between Secondary User and Primary User, represented by PER_{coll}. The PER_{coll} has been given as:

$$\mathrm{PER}_{\mathrm{coll}} = = 1 - e^{(L+H)/(r*T_{off})} \tag{3}$$

Where packet length is denoted as L, H is header length and R is transmission data rate of Secondary User.

2.5.3 Channel path loss model:

The reduction of power of a signal due to the distance travelled in a wireless channel is considered as path loss. Path loss should be estimated to measure the SNR from the source to the receiver. Various path loss models are there to calculate the signal attenuation in the channel and the standard one is taken here. The received power (P_r) related to transmitted power (P_t) is shown as below

$$P_r = P_t K \left(\frac{do}{d}\right)^{\gamma} \tag{4}$$

K, d_0 and γ are assumed to be same for every hop. The SNR is to be calculated between the information sensor and the first stage relaying sensor as reference for standard values of K, d_0 and γ. Now the SNR between any two nodes which are *i* hops distant with other has been calculated as

$$SNR_j = SNR \times (1/i)^{\gamma} \tag{5}$$

The modulation we are using here is Binary Phase Shift Keying (BPSK). The BER (P_b) for is Binary Phase Shift Keying for a specific SNR can be stated as

$$P_b^{BPSK} = Q(\sqrt{2}SNR) \tag{6}$$

2.6 Latency and Energy utility Analysis

In CR armed Wireless Body Area Network during the transmission, the message packet may corrupted by path loss and also by collision with Primary User. PER can calculated with the help of PU active model and path loss model which were shown in prior sections. Here expected energy utilization and latency is computed. PER plays a major role in finding both energy utilization and latency.

2.6.1 Latency analysis:

Generally, latency depends on various issues like processing capability of nodes, frequency of retransmissions and the hops needed to reach the sink. The latency mostly relies on effective handling of retransmissions. The primary theme of this work is to test the error control techniques performances for CR armed Wireless Body Area Network. Here latency is calculated with the number of retransmissions.

The expected retransmissions can be calculated from PER. In CR armed Wireless Body Area Network, PER is effected by both PER_{coll} and PER of specific error correction method. And the real PER is given as

$$PER=1 - (1 - PER_{coll})\,(1 - PER_{AB}) \tag{7}$$

On account of PER, expected number of retransmissions can be given as

$$E\,[N] = 1/\,(1 - PER) \tag{8}$$

For finding the total number of expected retransmissions can be gotten by adding all the retransmissions from each hop from source to destination.

2.6.2 Energy consumption Analysis:

The total energy consumed in communication when the data send from the sender to receiver is the addition of energy taken to transmit data and energy taken to receive data. And is given as

$$E_{cons} = E_{TX} + E_{RX} \tag{9}$$

Where E_{TX} is utilization of energy at the transmitter and E_{RX} is utilization of energy at the receiver. Total utilization of energy for single hop is given as

$$E_{cons} = E[N] \times (E[P_{TX}]\, t_{TX} + E[P_{RX}]\, t_{RX}) \tag{10}$$

Where E[N] is expected number of retransmissions, $E[P_{TX}]$ is power expected for transmission, t_{TX} is time taken for transmission and $E[P_{RX}]$ is the expected power for reception, t_{RX} is time taken for reception.

For simplicity, both t_{TX} and t_{RX} are taken as t. And moreover t is expressed as the multiple of number of bits transmitted with the time required to transmit one bit data which is denoted by t_b. Now t for fixed packet length L, header length H and for a code rate of error correcting code R_c can be given as

$$t_{TX} = t_{RX} = t = (R_c \times L + H)\, t_b \tag{11}$$

By using above formulas Energy utilization is given as

$$E_{cons} = E\,[N] \times (E[P_{TX}] + E[P_{RX}]) \times (R_c \times L + H)\, t_b \tag{12}$$

To compare the energy utilization the above formula is normalized. For single hop transmission normalized energy can be written as

$$E_{cons} = E\,[N] \times \left(\frac{\frac{L}{Rc} + H}{L+H} \right) \tag{13}$$

2.7 Summary

Low energy consumption is the primary aim in Body Area Networks to protect the human body due to the placement of sensors inside the body. There applications of body area network in healthcare is tremendous. Energy consumption can be reduced by implementing CR technique in WBAN. Energy consumption and latency are analysed by considering the Primary User activity and path loss due to the transfer of signal which depends mainly on distance.

3

Existing Error Control Mechanisms

3.1 Introduction

Error correction techniques which are also called as error control techniques enables authentic delivery of information over unreliable communication channels. Every communication channel is subjected to channel noise, so errors will occur at the time of transmission of data from source to a receiver. Generally, Error detection technique allows detecting of errors in received data, whereas error correction techniques are used to reconstruction of the original data.

Error correction and detections involves in adding redundant bits to original data while transmission. By using this receivers can check the reliability of the received message, and corrupted data can be recovered. There are two types of Error correction and detection schemes are present named systematic and non-systematic: In the former scheme, fixed number of parity bits are attached to the original data send by transmitter which are formed using predefined algorithms. These algorithms enables the receiver to detect the error by comparing the original data with the received data. Received bits are found to be wrong if it is mismatched. In non-systematic scheme original data is encoded first then encoded message is subjected to transmission. Here minimum encoded bits are equal to original message bits.

Error correcting codes are broadly categorized into two types.

(1) Automatic Repeat Request

(2) Forward Error Correction

3.2 Automatic Repeat Request

ARQ is a method of error controlling. During the data transmission in ARQ, it uses acknowledgements which is a message signal sent by the receiver as the indication receiving correct data packet and timeouts indicates a specific time period elapsed before receiving the acknowledgment to achieve authentic data transmission over an unreliable service. Sender will retransmit the frame or packet in the absence of acknowledgment before timeout. Sender retransmits the data frame till either it receives the acknowledgment or exceeds a specific number of predefined retransmissions.

Packet error Rate for ARQ can be calculated for single transmission for packet length L, header length H as

$$PER_{ARQ} = 1-(1-P_b)^{L+H} \quad (14)$$

3.3 Forward Error Correction

FEC technique is the method of fixing parity data or redundant data, to original packet to recover the data packet at the receiver even the error is occurred in the channel up to the capacity of a specified scheme. In this technique receiver need not call for the sender to retransmit the message, and therefore back channel is not necessary in FEC.

Error-correcting codes are generally divided into two types named block and conventional codes. Conventional codes operated in bit by bit method whereas block codes are operated on block by block process. In these two block codes more efficient. Hamming codes comes under block codes. The other examples are Reed Solomon codes which are notable for its current widespread using.

3.4 Cognitive Forward Error Correction:

Basically, as mentioned earlier error correcting techniques is categorized into two types named FEC and ARQ. In case of ARQ, a frame is transmitted again if it is founded that the frame is corrupted. Those frames are transmitted multiple times till they reach receiver without any error. Due to large number of retransmissions there will be more energy consumption and latency in ARQ. This is the major disadvantage of Automatic Repeat request. In Forward Error Correction, a predefined length of redundant bits are added to message to correct respective amount of bit errors at receiver. The main disadvantage in this method is cost due to redundancy. Redundancy augments packet size which leads to increase in encoding and decoding techniques. In Cognitive Radio system, paths changes frequently and nodes also changes as well. Here fixed amount of redundancy and error correcting method may not give best results every time.

The flow chart for Cognitive Forward Error Correction mechanism is given in Figure

3.1. The steps followed to select less hops and best error correcting technique in Cognitive Forward Error Correction is given below.

(1) A path request message is sent by the source.

(2) Source receives path reply message from sink.

(3) Multiple choices of all possible path reply messages are sent to source.

(4) Steps 5 to 9 are to be repeated for every possible route.

(5) SNR of each and every channel is calculated by path loss model.

(6) The mean Toff time SNR of each and every channel is calculated by Primary User Activity model.

(7) PER can be calculated for ARQ, Reed Solomon and LDPC codes.

(8) Latency is now calculated from PER using the formulae mentioned in Chapter 2.

(9) Expected energy utilization is computed the computed from latency given in Chapter 2.

(10) On the account of calculated energy for different paths and error correcting techniques, best path and coding technique is selected.

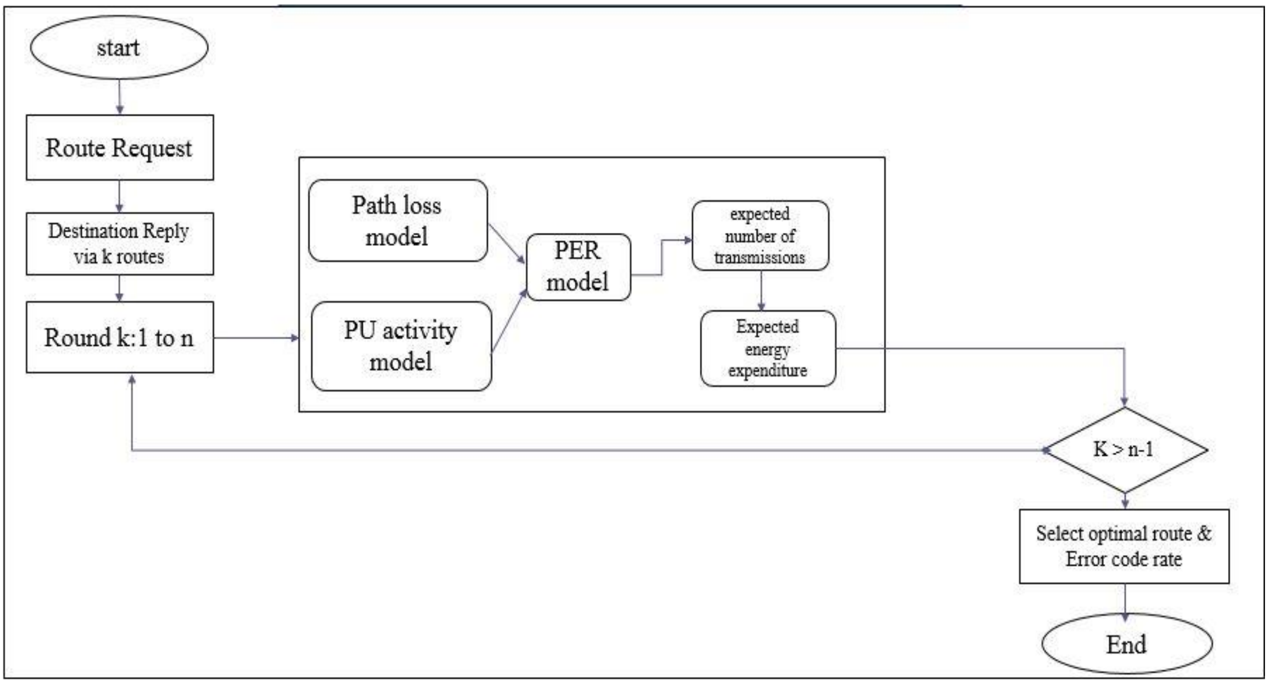

Figure 3.1 flow diagram for Energy consumption calculation [5]

3.5 Network Scenario:

In CR armed Wireless Body Area Network various paths are present from source to destination. The network scenario here taken for simulations are given in Figure 3.2. 11 hops have been considered in the scenario where one hop is taken as source which collects the biological data from the human body, one hop considered as destination which collects the data to transfer it to PDA and all the remaining are considered as relaying sensors. It is considered that relaying sensors do not collects any biological information it just relay the information to the sink.

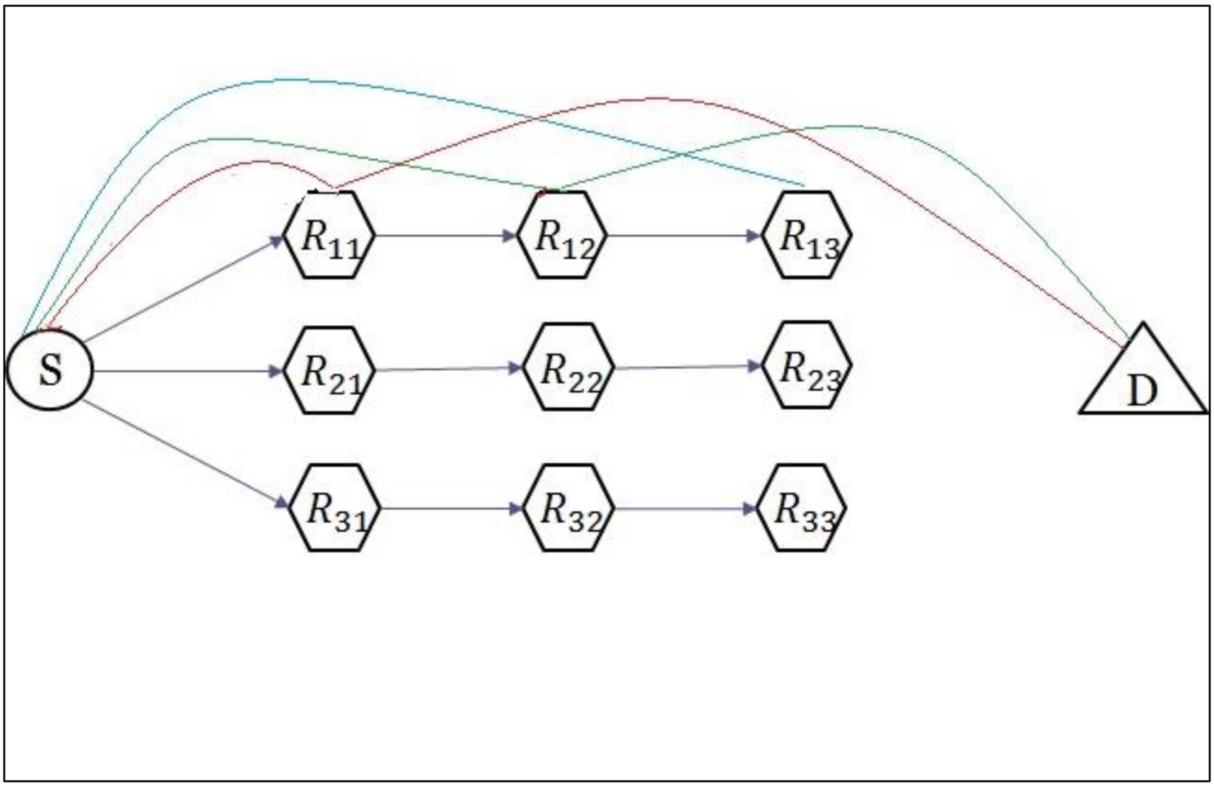

Figure 3.2 Network scenario for CR based Wireless Body Area Network [5]

Here it is taken that maximum distance from source to destination is 4 hops. There are various paths present in this scenario. Different paths are shown in different colours in the figure above. The information may take 1 hop route, 2 hops route or 3hops route to reach the destination. These sensors are numbered from 1 to 11 where hop 1 is the source, hop 11 is the sink and the hops from 2 to 10 are relaying sensors. It is considered that we know the distance between the hops and are kept equidistant. 28 routes have been gotten from source to sink and 1 hop route, 2 hops routes and 3hops routes are shown in Tables 3.1, 3.2 and 3.3 respectively.

1 hop path

1	11

Table 3.1: 1 hop route

2 hop paths

1	2	11
1	3	11
1	4	11
1	5	11
1	6	11
1	7	11
1	8	11
1	9	11
1	10	11

Table 3.2: routes with 2 hops

3 hop paths

1	2	3	11
1	2	4	11
1	3	2	11
1	3	4	11
1	4	2	11
1	4	3	11
1	5	6	11
1	5	7	11
1	6	5	11
1	6	7	11
1	7	5	11
1	7	6	11
1	8	9	11
1	8	10	11
1	9	8	11
1	9	10	11
1	10	8	11
1	10	9	11

Table 3.3: routes with 3 hops

3.5 Simulation Study and Analysis:

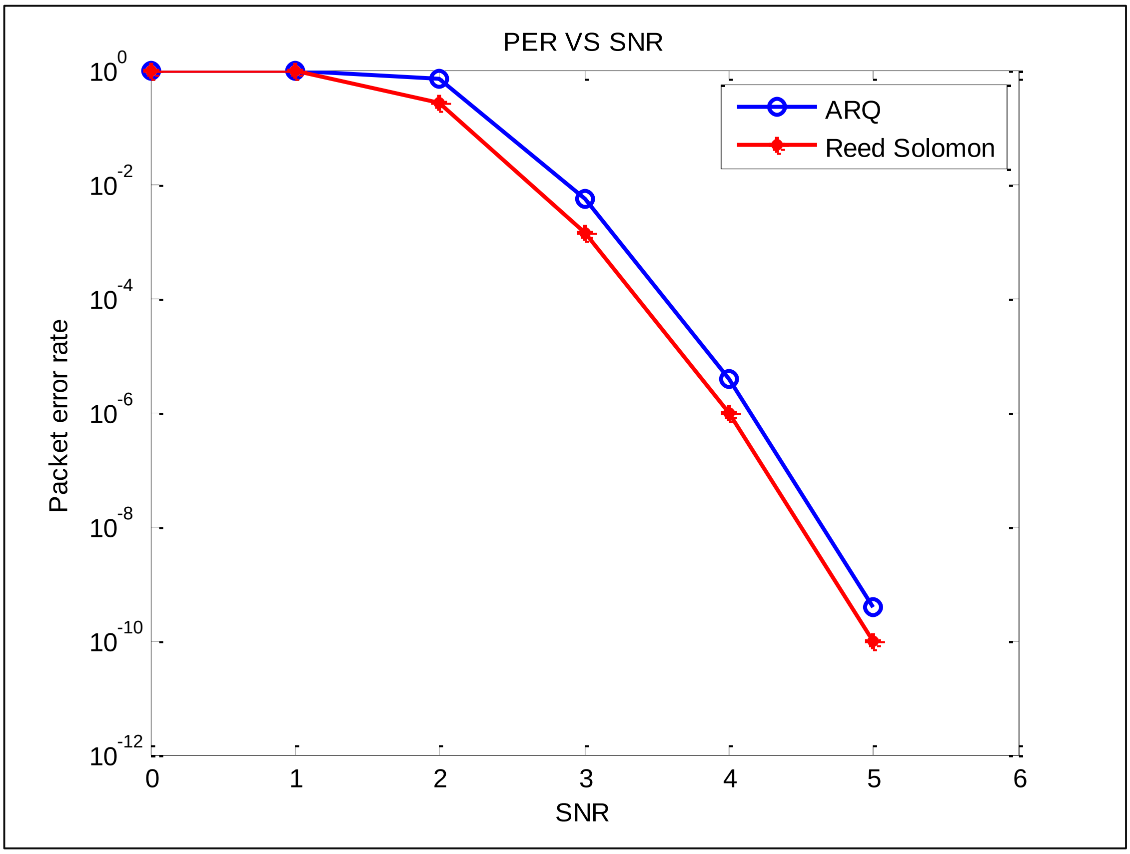

Figure 3.3 PER Comparison of ARQ and RS

Error correcting Techniques	Packet Error Rate		
	SNR 4dB	SNR 5dB	SNR 6dB
ARQ	9×10^{-02}	2×10^{-03}	4.6×10^{-06}
Reed Solomon	2×10^{-02}	5×10^{-04}	1.1×10^{-06}

Table 3.4: PER Comparison of ARQ and RS

- As the SNR increases Packet Error Rate decreases due to the increase in strength of signal with respect to the noise.
- Reed Solomon code has given better performance as compared to ARQ.

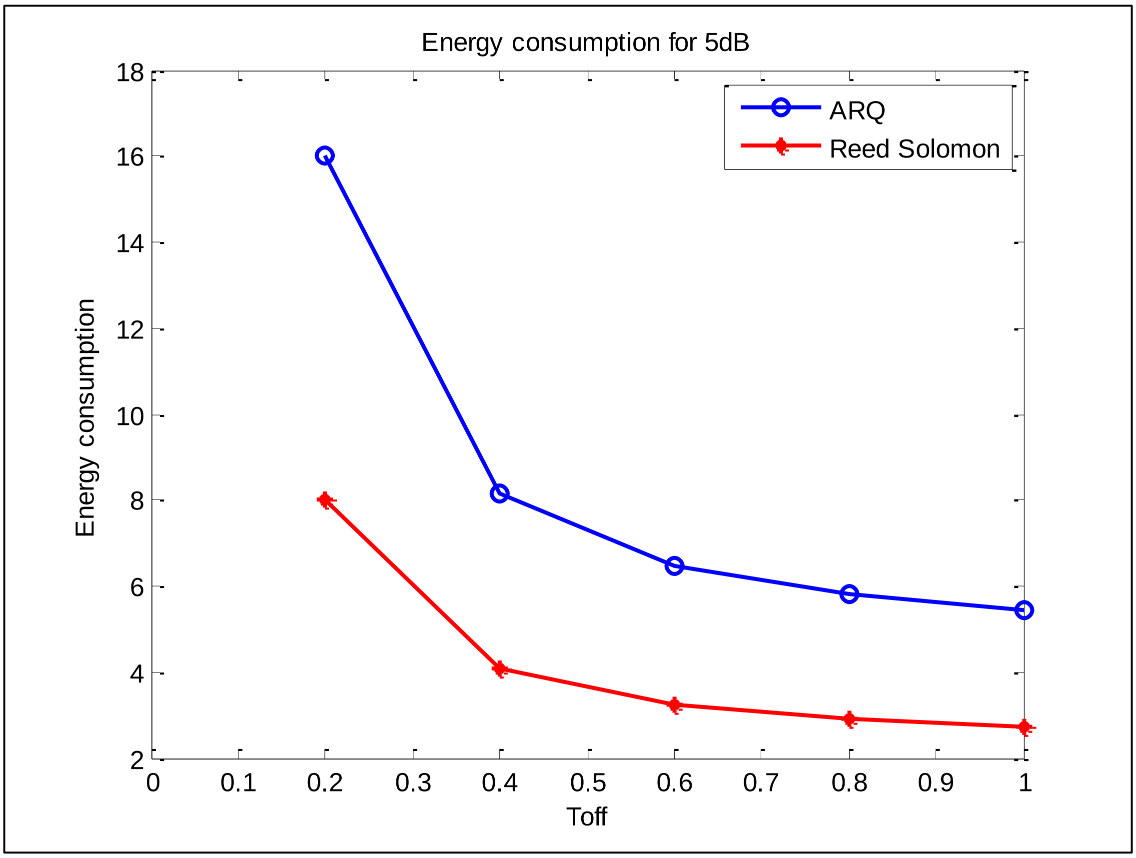

Figure 3.4 Expected energy consumption comparison of ARQ and RS at SNR 5dB

Error correcting Techniques	Packet Error Rate		
	T_{off}=0.4	T_{off}=0.6	T_{off}=0.8
ARQ	8.1	6.4	5.7
Reed Solomon	4	3.2	2.8

Table 3.5 Expected energy consumption comparison of ARQ and RS at SNR 5dB

- As SNR increases Energy consumption becomes low because of having sufficient energy to reach distant hops hence avoids number of hops for transmission.
- Energy consumption deceases as the PU active time is less as there are less collision between primary user and secondary user.
- RS error correcting technique improves 2.4 mv energy as compared to ARQ.

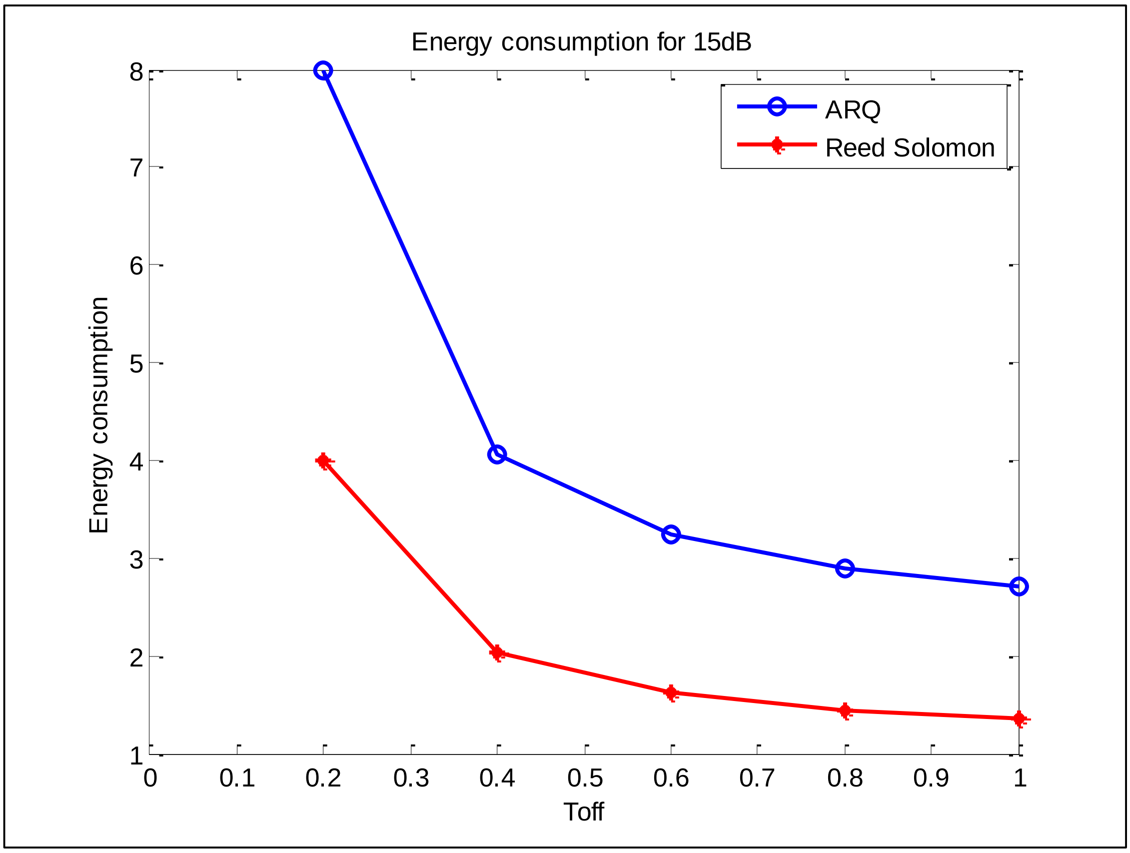

Figure 3.6 Expected energy consumption comparison of ARQ and RS at SNR 15dB

Error correcting Techniques	Packet Error Rate		
	T_{off}=0.4	T_{off}=0.6	T_{off}=0.8
ARQ	4	3.23	2.9
Reed Solomon	2	1.6	1.44

Table 3.6 Expected energy consumption comparison of ARQ and RS at SNR 15dB

- As SNR increases Energy consumption becomes low because of having sufficient energy to reach distant hops hence avoids number of hops for transmission.
- As the number of hops decreases to reach destination energy consumption also decreases due to low retransmissions.

- RS error correcting technique improves 1.2 mv energy as compared to ARQ.

3.6 Summary

Error correcting techniques are of enormous importance in minimizing the packet error rate (PER). PER is the factor to calculate how correctly a message packet received. Less PER gives less number of retransmissions from source which led to low energy consumption and time delay. ARQ gives more delay due to large number of retransmissions. Reed Solomon codes results 2.4 improvement at SNR 5dB and 1.2 improvement at SNR 15dB when compared with ARQ. The RS codes results in around 1dB of improvement of PER when compared to Automatic Repeat request.

But the performance of LDPC codes are superior to the optimal Reed Solomon code and ARQ code.

4

Proposed Error Control Mechanisms

4.1 Introduction

In Automatic repeat request message will be retransmitted till it reached the receiver error free. In noisy channels due to more noise present in channel more number of retransmissions will occur. Due to more retransmissions time delay will be increased. This is the main drawback for ARQ. In the case of forward error correction technique loss present in terms of redundancy. As the redundancy increases packet cost will increase accordingly and in CR based Wireless Body Area Network path should be selected adaptively. So fixed amount of redundancy cannot give desirable results. So CFEC mechanism is used which is able to select the best error correcting technique and redundancy for it. So we go for broadly using error correcting technique LDPC codes.

4.2 Low Density Parity Check (LDPC) codes

LDPC codes or Gallager codes are error correcting codes. There are the method for transmission of a message through an unreliable channel. LDPC codes are constructed with a bipartite graph where non-zero elements are sparsely arranged. These codes are used for capacity-approach, which indicates that its practical construction permits the threshold of noise can keep close to the Shannon limit. Shannon limit is maximum theoretical value for a symmetrical memoryless channel. The threshold of noise gives the upper limit of noise in the channel can be present, till where the probability of information lost can be kept as low as required.

LDPC codes come under block codes. These are the codes contains parity-check matrices with sparsely arranged non-zero entries. Except the parity check matrix PCM) to be sparse, The LDPC code has no difference with other block codes. Iterative decoding algorithm which is used for LDPC codes can be used for existing conventional block codes also, if they are represented with sparsely arranged parity check matrix. The decoding technique for the LDPC codes and conventional block are different. The design properties of parity check matrix are needed to be focused.

A regular LDPC code where PCM contains rows as m and columns as n will have,

$$m \cdot w_r = n \cdot w_c \tag{16}$$

The bit error rate for the LDPC codes at the receiver could be evaluated as an iterative function which rely on the bit error probability of previous iteration. The BER for LDPC code after *i* iterations is given as below

$$P_{i+1} = P_o - P_o \left(\sum_{t=b}^{dl-1} \binom{dl-1}{t} \left(\frac{1+(1-2P_i)^{dr-1}}{2}\right)^t \left(\frac{1-(1-2P_i)^{dr-1}}{2}\right)^{dl-1-t}\right) + (1-P_o) \left(\sum_{t=b}^{dl-1} \binom{dl-1}{t} \left(\frac{1-(1-2P_i)^{dr-1}}{2}\right)^t \left(\frac{1+(1-2P_i)^{dr-1}}{2}\right)^{dl-1-t}\right) \tag{17}$$

Where P_i is the bit error rate of previous iteration, Po is the bit error rate of BPSK modulation without using any error correcting technique.

Packet error rate can be calculated from bit error rate as

$$PER_{LDPC} = 1-(1-P_{i+1})^{L+H} \tag{18}$$

To minimize the value of P_{i+1}, threshold value b is chosen as below. For this odds to be right previously is compared with odds to be correct using check nodes.

$$\frac{1-Po}{Po} \leq \left[\frac{1+(1-2P_i)^{dr-1}}{1-(1-2P_i)^{dr-1}}\right]^{2b-dl-1} \tag{19}$$

4.3 Simulation Study and Analysis

Parameters for simulation is taken go get the results to analyse ARQ, Reed Solomon and LDPC codes are given below Table 4.1

PARAMETERS	VALUES
L	512 bits
H	30 bits
T_{off}	0.8
R	2 kbps
SNR	10
FEC	BCH codes
Modulation	BPSK

Table 4.1: simulation parameters

ASSUMPTIONS:

- It is assumed that distance between all the hops present in the network are known and those are placed in equal distance of 1 metre from the immediate neighbour nodes.
- Assumed that Primary User activity is same for all the nodes and set it as 0.8.
- The sink is at the maximum of 4 hops distant from from the source.

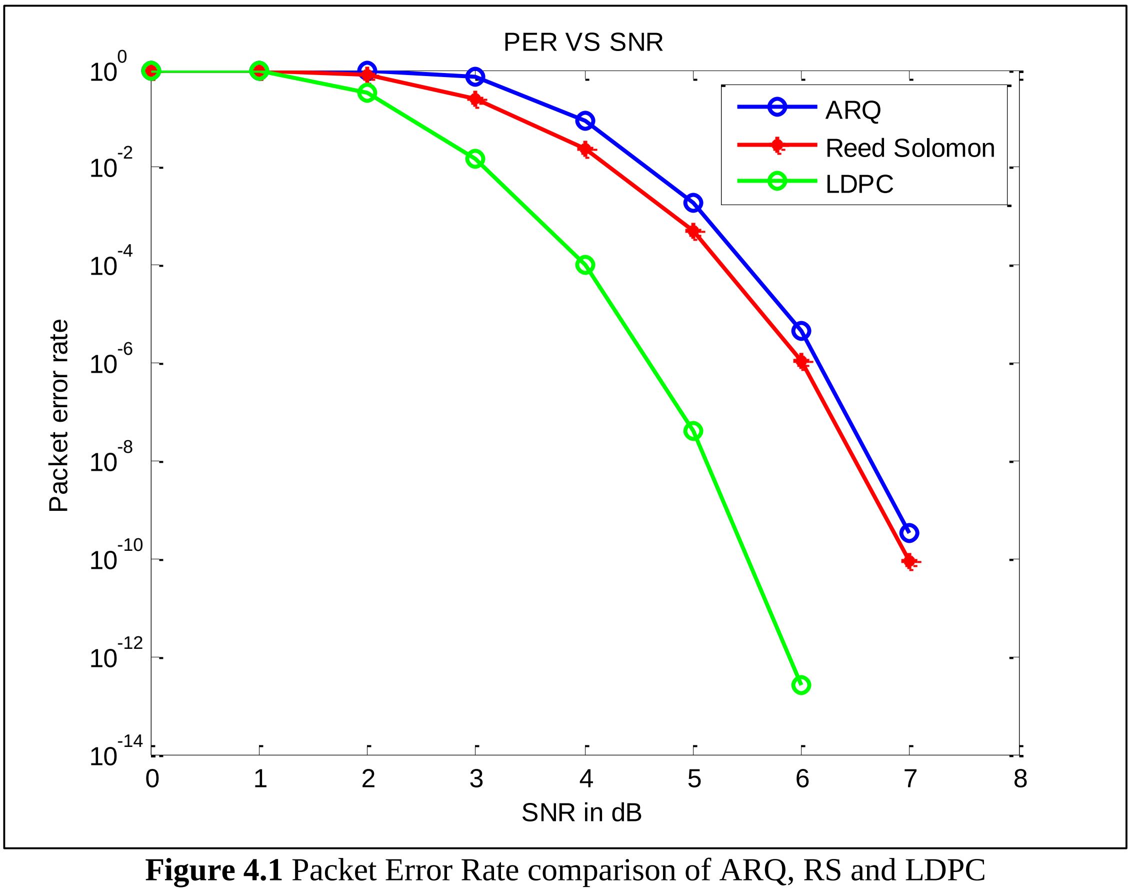

Figure 4.1 Packet Error Rate comparison of ARQ, RS and LDPC

Error correcting Techniques	Packet Error Rate		
	SNR 4dB	SNR 5dB	SNR 6dB
ARQ	9×10^{-02}	2×10^{-03}	4.6×10^{-06}
Reed Solomon	2×10^{-02}	5×10^{-04}	1.1×10^{-06}
LDPC	9×10^{-05}	4×10^{-08}	2×10^{-13}

Table 4.2 Packet Error Rate comparison of ARQ, RS, LDPC

- Packet error rate is very low in LDPC as compared to Reed Solomon and ARQ which gives rise to less number of retransmissions.

4.3.1 Energy consumption for different SNR values:

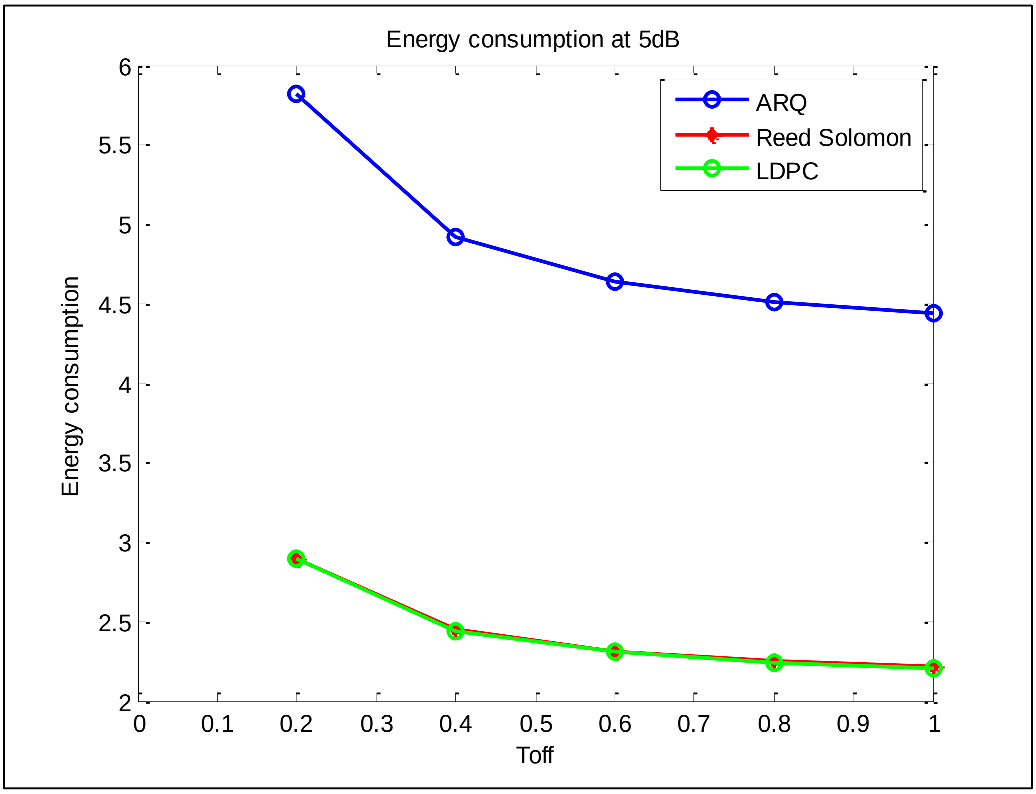

Figure 4.2 Energy consumption comparison of ARQ, RS, and LDPC at SNR 5dB

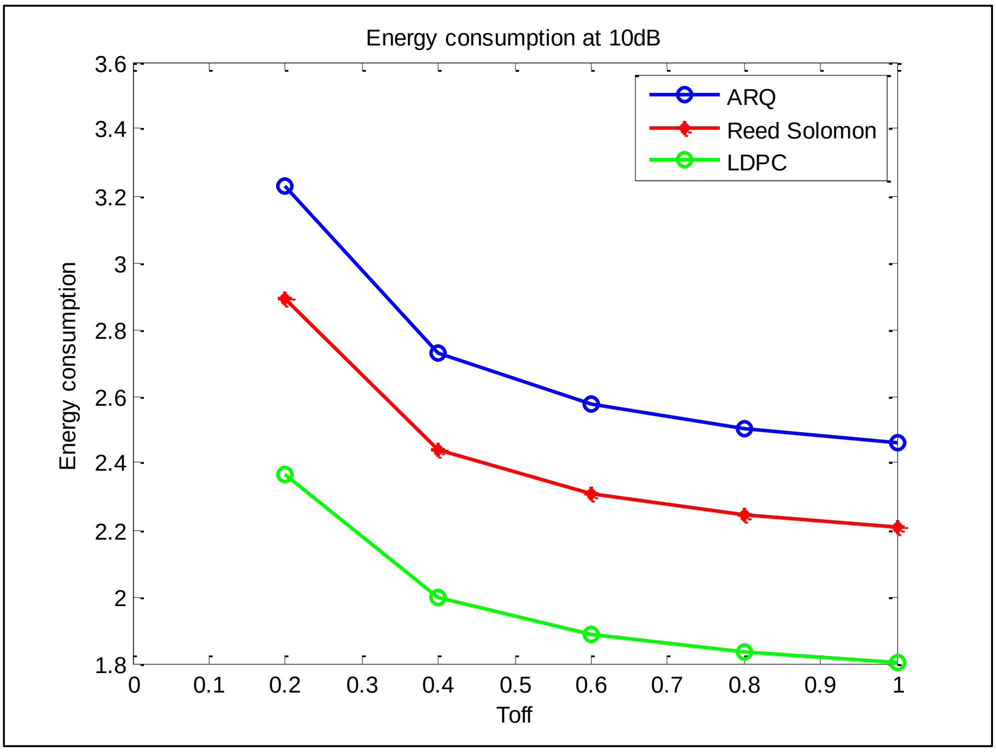

Figure 4.3 Energy consumption comparison of ARQ, RS, and LDPC at SNR 10dB

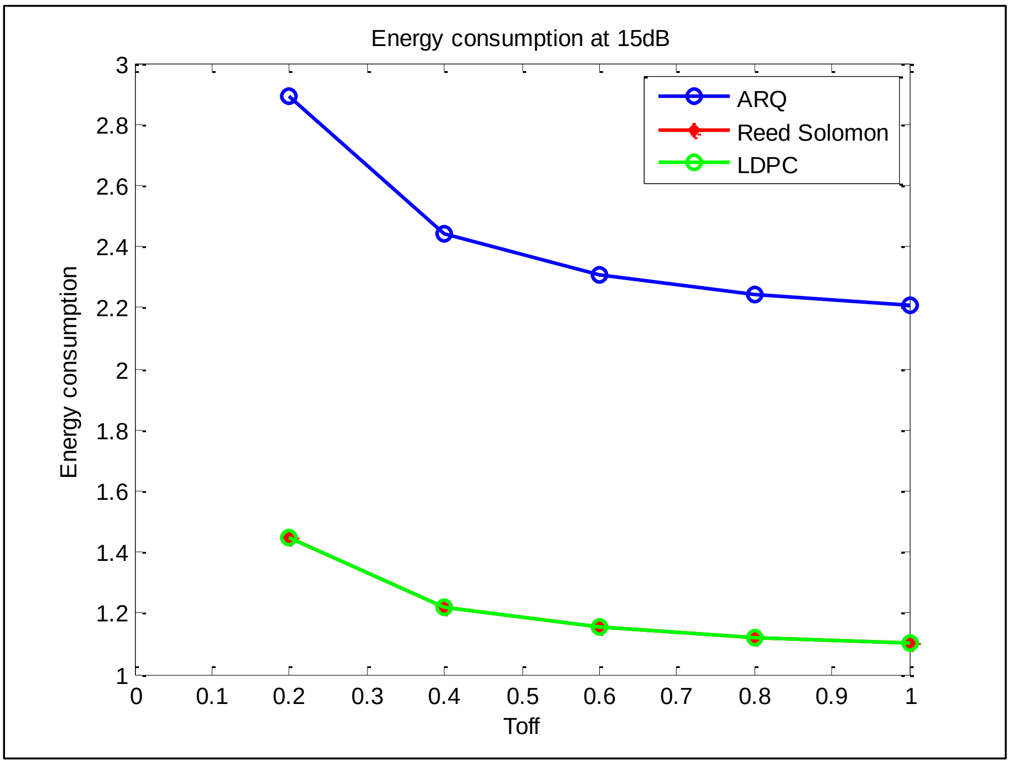

Figure 4.4 Energy consumption comparison of ARQ, RS, and LDPC at SNR 15dB

Comparison of results:

Here Energy consumption is compared for ARQ, Reed Solomon and LDPC error correcting codes for different SNR values by changing PU activity from 0 to 1.

At T_{off} =0.5

	ARQ	Reed Solomon	LDPC
5dB	4.9	2.45	2.44
10dB	2.7	2.4	1.99
15dB	2.4	1.2	1.2

Table 4.3: Energy consumption of ARQ, RS, and LDPC for different SNR values

Conclusion:

- As SNR increases Energy consumption becomes low because of having sufficient energy to reach distant hops hence avoids number of hops for transmission.
- As the number of hops decreases to reach destination energy consumption also decreases due to low retransmissions.
- Energy consumption deceases as the PU active time is less as there are less collision between primary user and secondary user.

4.3.2 Energy consumption for different data rate values:

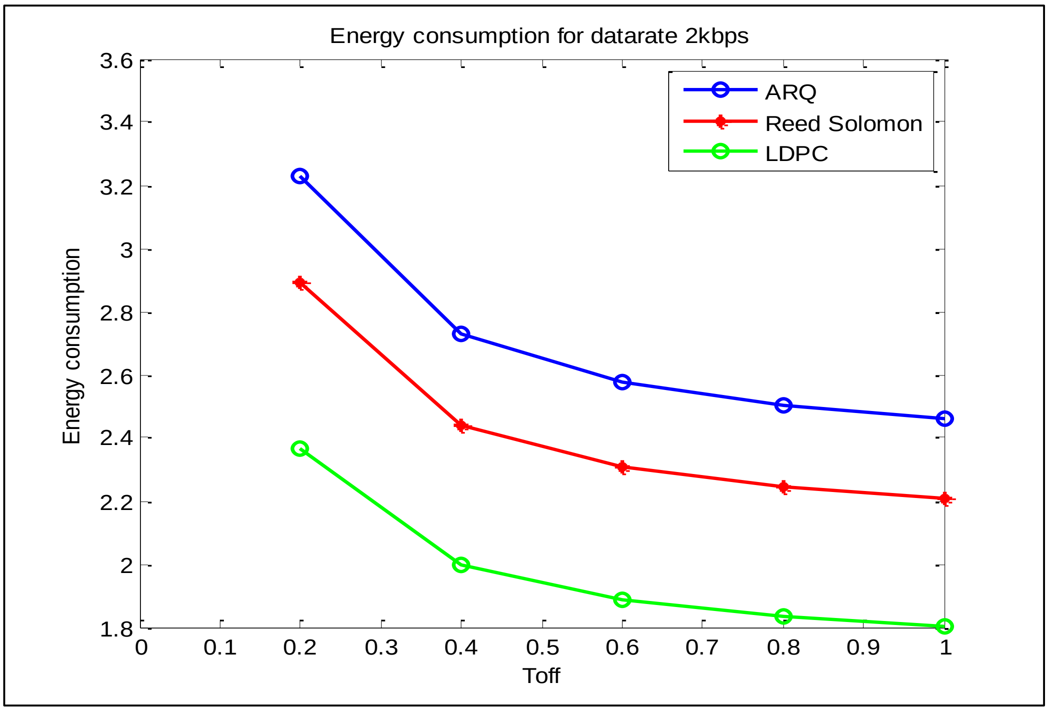

Figure 4.5 Energy consumption comparison of ARQ, RS, and LDPC at data rate 2kbps

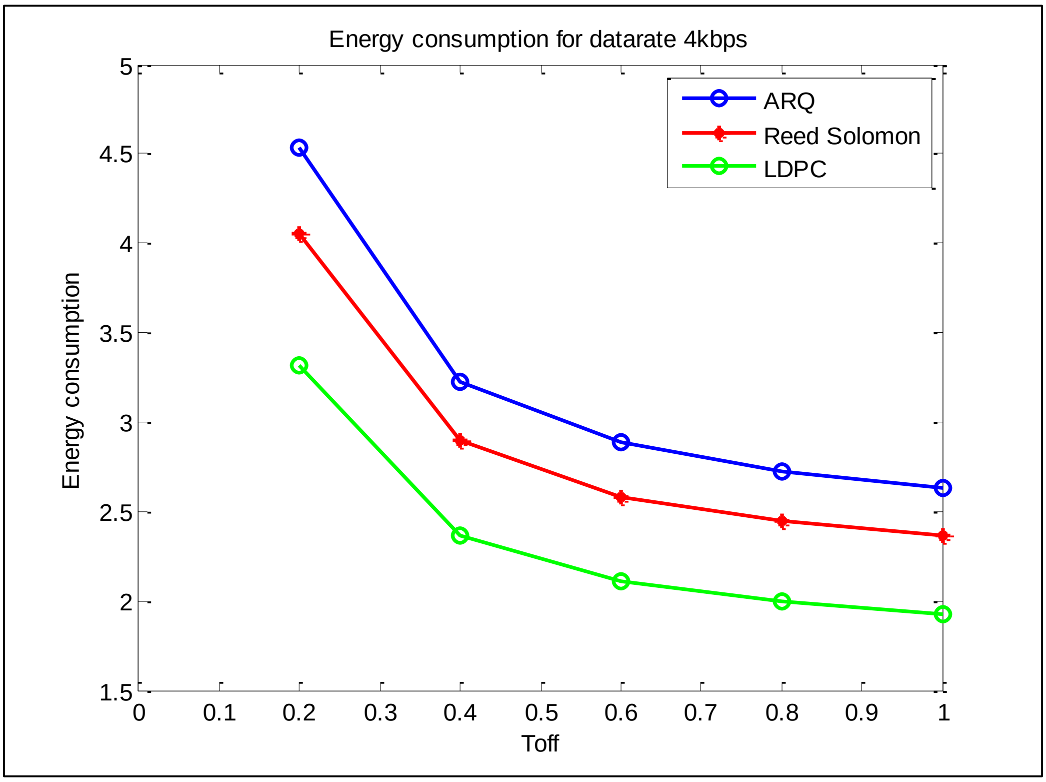

Figure 4.6 Energy consumption comparison of ARQ, RS, and LDPC at data rate 4kbps

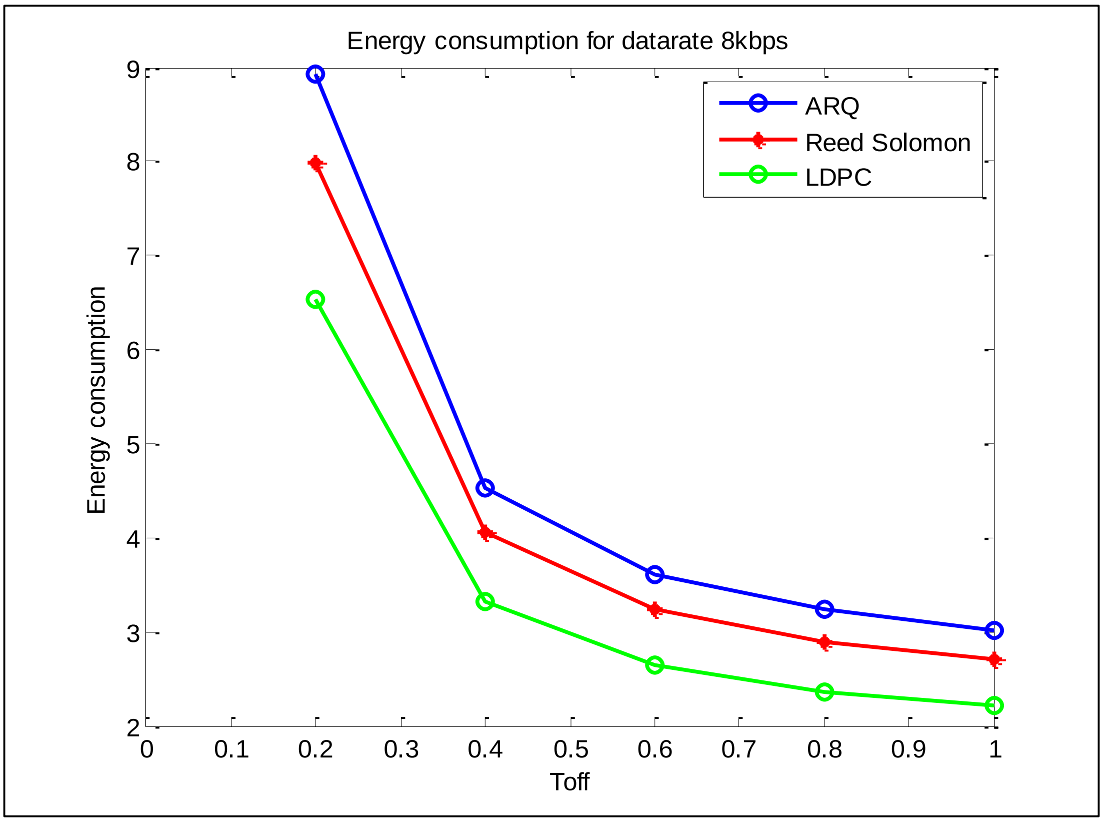

Figure 4.7 Energy consumption comparison of ARQ, RS, and LDPC at data rate 8kbps

Here Energy consumption is compared for ARQ, Reed Solomon and LDPC error correcting codes for different data rates by changing PU activity from 0 to 1.

At T_{off} =0.5

	ARQ	**Reed Solomon**	**LDPC**
2kbps	2.7	2.4	1.99
4kbps	3.2	2.89	2.36
8kbps	4.5	4	3.3

Table 4.4: Energy consumption for different data rates

- As data rate increases allows secondary user to take more time to transmit data so leads to high collisions and Energy consumption.
- Energy consumption deceases as the PU active time is less as there are less collision between primary user and secondary user.
- In all three cases LDPC gives better results as compared to ARQ and Reed Solomon.

4.3.3 Expected Energy consumption v/s SNR:

Effect on Expected Energy consumption by varying SNR value for LDPC, Reed Solomon and ARQ is shown in figure 4.8. As mentioned earlier destination is maximum at a distance of 4 hops. Here y is varied to show the impact of it on Energy consumption, which gives SNR between two nodes placed at minimum distance. T_{off}, which gives active time of primary user is kept constant as 0.8.

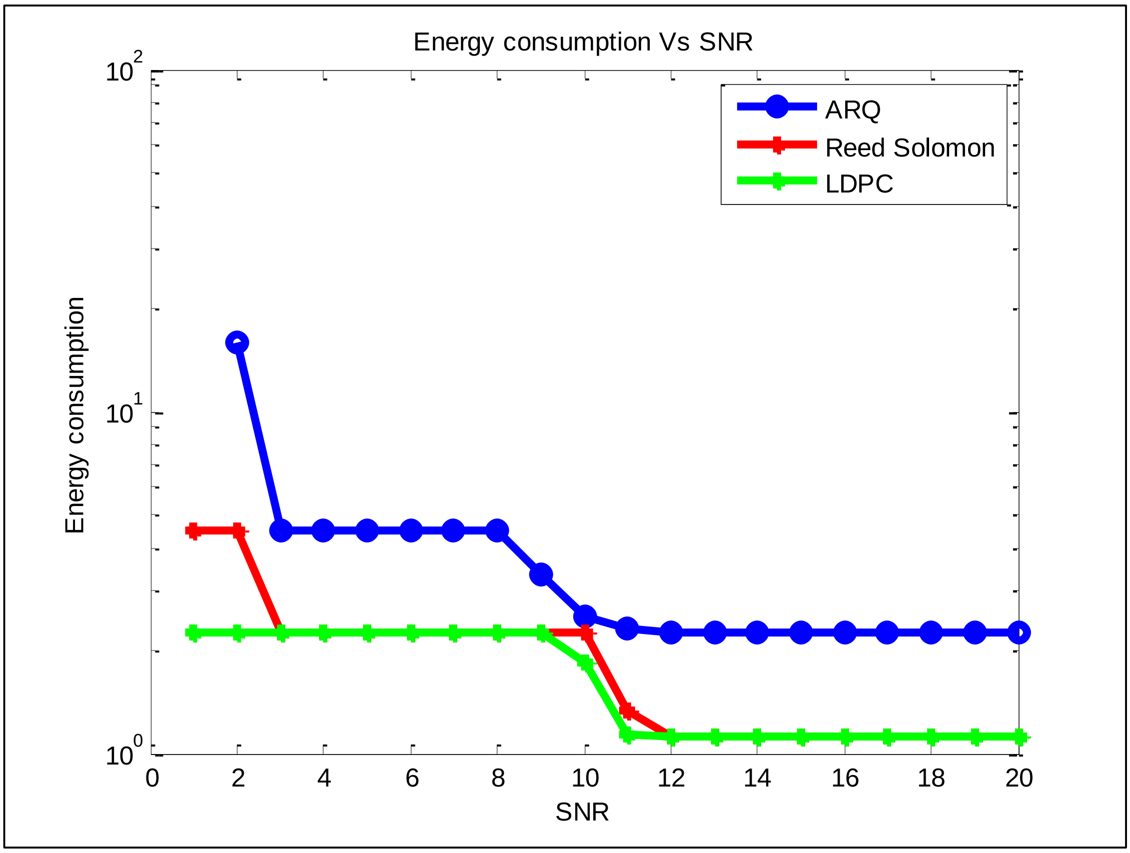

Figure 4.8 Expected Energy consumption comparison of ARQ, RS, and LDPC

- As SNR increases Energy consumption becomes low because of having sufficient energy to reach distant hops hence avoids number of hops for transmission.
- LDPC given best performance at 10dB compared to Reed Solomon and ARQ.
- For the channels having y less than 7dB LDPC out performs Reed Solomon and ARQ and for the channels having SNR less than 5dB ARQ given infinity Expected Energy consumption.

4.3.4 Adoption of routes for each error correction technique:

Table 4.3 shows the adoption of routes i.e. one hop, 2 hop and 3 hop routes for ARQ whereas Table 4.4 shows the adoption of routes i.e. one hop, 2 hop and 3 hop routes for Reed Solomon and Table 4.5 shows the adoption of routes i.e. one hop, 2 hop and 3 hop routes for LDPC.

Scenario 1 (T_{off1}=1, T_{off2}=1, T_{off3}=1): it indicates all channels are not affected with PU activity which gives no collisions between Primary User and Secondary User.

Scenario 2 (T_{off1}=0.1, T_{off2}=1, T_{off3}=1): it shows first hop in all channels i.e. hops 2, 5 and 8 are not free and having Primary user.

Scenario 3 (T_{off1}=1, T_{off2}=0.1, T_{off3}=1): it indicates second hop in all channels i.e. hops 3, 6 and 9 are not free and having Primary user.

Scenario 4 (T_{off1}=1, T_{off2}=1, T_{off3}=0.1): it gives third hop in all channels i.e. hops 4, 7 and 10 are not free and having Primary user.

	3 hops route	2 hops route	1 hop route
T_{off1}=1, T_{off2}=1, T_{off3}=1	y<9dB	y>9dB	
T_{off1}=0.1, T_{off2}=1, T_{off3}=1	y<9dB	y>9dB	
T_{off1}=1, T_{off2}=0.1, T_{off3}=1			
T_{off1}=1, T_{off2}=1, T_{off3}=0.1	y<9dB	y>9dB	

Table 4.5: adoption of routes for ARQ for different scenarios

	3 hops route	2 hops route	1 hop route
$T_{off1}=1$, $T_{off2}=1$, $T_{off3}=1$	y<4dB	4dB<y<10dB	y>10dB
$T_{off1}=0.1$, $T_{off2}=1$, $T_{off3}=1$	y<4dB	4dB<y<10dB	y>10dB
$T_{off1}=1$, $T_{off2}=0.1$, $T_{off3}=1$			y>10dB
$T_{off1}=1$, $T_{off2}=1$, $T_{off3}=0.1$	y<4dB	4dB<y<10dB	y>10dB

Table 4.6: adoption of routes for Reed Solomon for different scenarios

	3 hops route	2 hops route	1 hop route
$T_{off1}=1$, $T_{off2}=1$, $T_{off3}=1$	y=1dB	1dB<y<9dB	y>9dB
$T_{off1}=0.1$, $T_{off2}=1$, $T_{off3}=1$	y=1dB	1dB<y<9dB	y>9dB
$T_{off1}=1$, $T_{off2}=0.1$, $T_{off3}=1$	y=1dB	1dB<y<9dB	y>9dB
$T_{off1}=1$, $T_{off2}=1$, $T_{off3}=0.1$	y=1dB	1dB<y<9dB	y>9dB

Table 4.7: adoption of routes for LDPC for different scenarios

- ARQ adopted 3 hop route for y<9dB and adopted 2 hop route for y>9dB and it never adopt 1 hop route. So it consumes more energy to send data.
- Reed Solomon technique adopted 3 hop route for y<4dB and adopted 2 hop route till 10dB and it adopt 1 hop route for SNR more than 10dB.
- LDPC adopted 2 hop more quickly than ARQ, Reed Solomon techniques for 1dB and it adopt 1hop route for SNR more than 9dB. So it shown abrupt improvement at SNR 10dB compared to Reed Solomon.

4.3.5 Energy consumption vs SNR and T_{off}

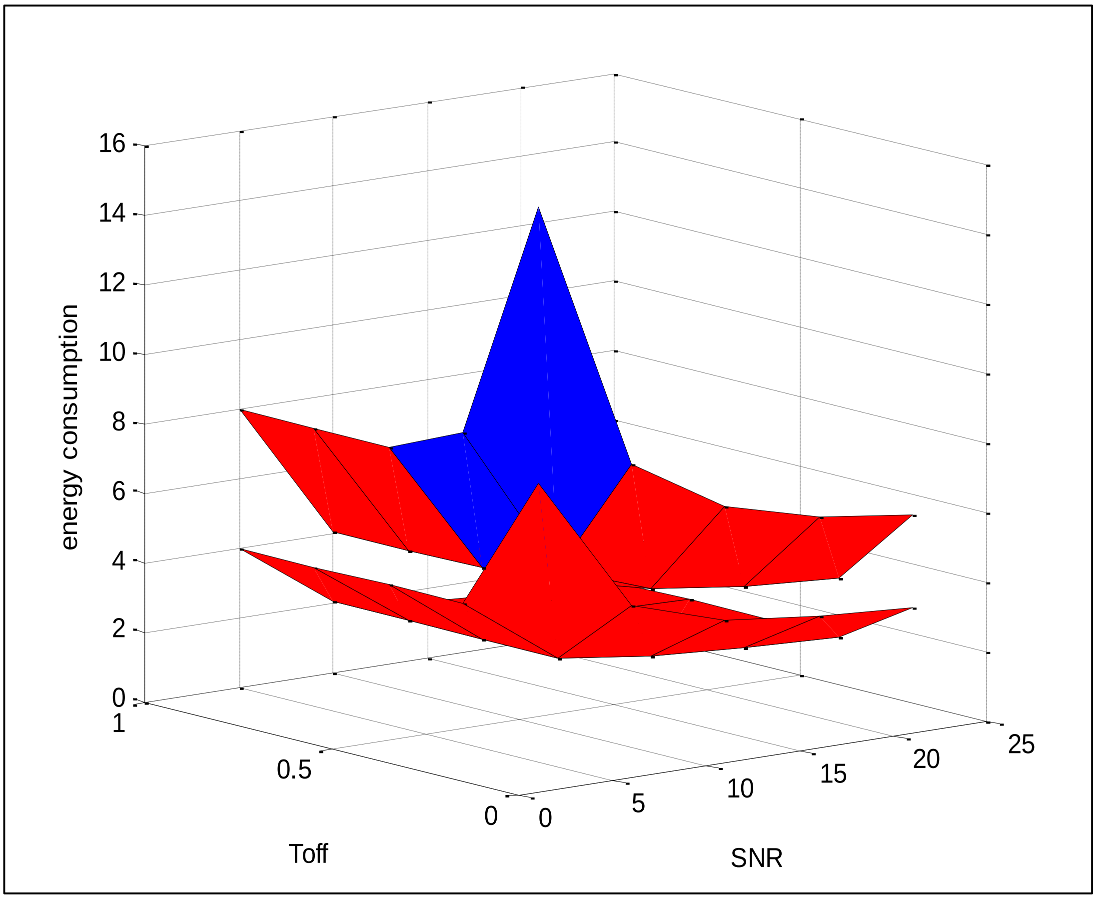

Figure 4.9 Expected Energy consumption v/s SNR and T_{off}

Figure 4.9 represents the impact of both activity of PU and SNR on Expected energy utilization.

Here T_{off} is kept constant and varied from 0 to 1 and SNR is varied from 1 to 25. It is evident in the result that as SNR increases PER decreases and makes the corruption in the packet is low which leads the energy consumption minimum.

As T_{off} time increases collision between SU, PU increases which leads to high PER and more number of retransmissions then it tends to high energy consumption.

4.4 Summary

Error correcting techniques are of enormous importance in minimizing the packet error rate (PER). PER is the factor to calculate how correctly a message packet received. Less PER gives less number of retransmissions from source which led to low energy consumption and time delay. ARQ gives more delay due to large number of retransmissions. LDPC codes results 2.46 improvement at SNR 5dB and 1.2 improvement at SNR 15dB when compared with ARQ. LDPC given better results of energy consumption at different data rates when compared with Reed Solomon and automatic repeat request.

5

Conclusion and Future Scope of Research

5.1 Conclusion

This thesis explains the remarkable advantages of LDPC, Reed Solomon codes in terms of packet loss, expected energy and latency utilization for Cognitive Radio armed Wireless Body Area Networks. LDPC and Reed Solomon has low energy utilization compared to ARQ. Furthermore, LDPC and Reed Solomon codes with Cognitive Forward Error Correction mechanism are able to reach the sink with less number of hops, which shows the importance of CFEC mechanism in minimizing the time consumption when compared to ARQ. LDPC and RS codes gives better results with CFEC mechanism when we know the channel conditions like Primary User activity and SNR.

- As SNR increases Energy consumption becomes low because of having sufficient energy to reach distant hops hence avoids number of hops for transmission.
- As the number of hops decreases to reach destination energy consumption also decreases due to low retransmissions.
- Energy consumption deceases as the PU active time is less as there are less collision between primary user and secondary user.
- As data rate increases allows secondary user to take more time to transmit data so leads to high collisions and Energy consumption.
- In all three cases LDPC gives better results as compared to ARQ and Reed Solomon.

5.2 Future Scope of Research

WBAN is the best option for the human healthcare in the upcoming years. Energy and time consumption are the two main prerequisites in Wireless Body Area Networks. As we seen LDPC Codes given better results.

- Consumption of energy and latency can be reduced by changing various other error correcting codes.
- Various techniques can be used to find the routes which takes less time for detection of best possible paths.

REFERENCES

[1] Li, Huan-Bang, and Ryuji Kohno. "Body area network and its standardization at *IEEE 802.15. BAN." Advances in Mobile and Wireless Communications*. Springer Berlin Heidelberg, 2008. 223-238.

[2] Barakah, Deena M., and Muhammad Ammad-uddin. "A survey of challenges and applications of wireless body area network (WBAN) and role of a virtual doctor server in existing architecture." *Intelligent Systems, Modelling and Simulation (ISMS), 2012 Third International Conference on*. IEEE, 2012.

[3] Yazdandoost and Sayrafian," Wireless Personal Area Networks", IEEE P802.15-08-0780-09-0006

[4] Movassaghi, Samaneh; Abolhasan, Mehran and Lipman, Justin and Smith, David and Jamalipour, Abbas (2014). "Wireless Body Area Networks: A Survey". IEEE Communications Surveys and Tutorials (IEEE)

[5] Najam ul Hasan, Waleed Ejaz, Mahin K. Atiq and Hyung Seok Kim," Energy-efficient error coding and transmission for cognitive wireless body area network" in INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS Int. J. Commun. Syst. (2015)

[6] Deepak KS, Babu AV. Improving energy efficincy of incrmental relay based cooperative communications in wireless body area networks. International Journal of Communication Systems 2015; 28(1): 91–111

[7] Chen, Junbin, Lin Wang, and Yong Li. "Performance comparison between non-binary LDPC codes and Reed-Solomon codes over noise bursts channels." *Communications, Circuits and Systems, 2005. Proceedings. 2005 International Conference on*. Vol. 1. IEEE, 2005.

[8] Joshi, Gyanendra Prasad, Seung Yeob Nam, and Sung Won Kim. "Cognitive radio wireless sensor networks: applications, challenges and research trends." *Sensors* 13.9 (2013): 11196-11228.

[9] Johnson, Sarah J. "Introducing low-density parity-check codes." *University of Newcastle, Australia* (2006).

[10] Rehman, O., et al. "An Energy Efficient Decoding Scheme for Wireless Body Area Sensor Networks." *arXiv preprint arXiv:1309.4374* (2013).

[11] Luby, Michael, et al. "Analysis of low density codes and improved designs using irregular graphs." *Proceedings of the thirtieth annual ACM symposium on Theory of computing*. ACM, 1998.

[12] Le Duc, A., C. J. Le Martret, and P. Ciblat. "Packet error rate and efficiency closed-form expressions for cross-layer hybrid ARQ schemes." *Signal Processing Advances in Wireless Communications, 2009. SPAWC'09. IEEE 10th Workshop on*. IEEE, 2009.

[13] El-Bendary, M. A. M., H. Kasban, and M. A. R. El-Tokhy. "Interleaved Reed-Solomon codes with code rate switching over wireless communications channels." *Proceedings of the 2nd International Conference on Advanced in Computer, Jul*. 2014.

[14] Akyildiz, Ian F., et al. "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: a survey." *Computer networks* 50.13 (2006): 2127-2159.

[15] Li X, Wang D, McNair J, Chen J. Residual energy aware channel assignment in cognitive radio sensor networks. IEEE Wireless Communications and Networking Conference (WCNC), Cancun, 2011; 398–403.

[16] Oto MC, Akan OB. Energy-efficient packet size optimization for cognitive radio sensor networks. IEEE Transactions on Wireless Communications 2012; 11(4): 544–1553.

[17] Gallager, Robert G. "Low-density parity-check codes." *Information Theory, IRE Transactions on* 8.1 (1962): 21-28.

[18] Garth V. Crosby, Tirthankar Ghosh, Renita Murimi, Craig A. Chin," Wireless Body Area Networks for Healthcare: A Survey" in International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC) Vol.3, No.3, June 2012

[19] Stenbit J. Table of generators for Bose-Chaudhuri codes (Corresp.). IEEE Transactions on Information Theory 1964; 10(4): 390–391.